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Procedia Engineering 44 (2012) 1454 – 1457

Procedia Engineering

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Euromembrane Conference 2012

[P2.117] Effect of flow configuration on the performance of gas-liquid membrane contactor

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In the gas-liquid or liquid-liquid membrane contactor operations, the process performance may be limited less by the membrane resistance than by the resistance of the fluids adjacent to it. This means that successful membrane process design must consider not only membrane chemistry and structure, but also flow configuration and module geometry. Most of the researches on the membrane-based contacting processes have been conducted on parallel flow module. The simplicity in manufacturing, the well known fluid dynamics in shell and tube side and the easiness of mass transfer estimation are the advantages of the parallel flow module, even though its disadvantage is mainly seen in its moderate efficiency in mass transfer compared with the cross-flow configuration [1,2,3]. However, the study of the cross-flow module in the membrane contacting process is limited, although it offers to the hybrid process the challenge of industrial application.

The present work focused on the experimental and theoretical analysis of mass transfer in a cross-flow membrane absorber. The commercial polypropylene hollow fiber Liqui-Cel® Extra-Flow membrane, with a diameter of 6.35 cm (2.5 in.) and a length of 20.32 cm (8 in.) was used, in order to evaluate the process performance in a bench-scale and cross-flow contactor. The gas-liquid systems were selected in order to simplify the conditions and to facilitate the mass transfer analysis. The study consists in the experimental evaluation of the membrane performance and the determination of the mass transfer phenomenon. Experiments of carbon dioxide absorption from pure gas, eliminating the mass transfer resistance in the gas phase, or a gas mixture containing 15% CO_2 in N_2, typical composition (in major components) of flue gases from a coal combustion power plant, in water, aqueous solutions of KOH and DEA were carried out. Considering that the highest cross-flow contactor performance is achieved when the fluid with the dominant resistant to mass transfer is flowing in the shell side [1], the membrane was used with gas flow in the lumen side and liquid flow on the shell side. Prior to each experiment a thorough drying procedure was used to remove any accumulated condensed water from the membrane pores, as described in previous published work [4].

Experimental results showed that the pure CO_2 mass transfer in water is weakly dependent on the gas flow rate, as presented in Figure 1, where the overall mass transfer coefficient is plotted versus the gas flow rate. Assuming that the membrane operates under the non-wetted mode for the experimental period, the analysis of the membrane and liquid resistances to mass transfer was performed to develop a shell side mass transfer correlation, Figure 2. The proposed correlation was compared with correlations from the literature and used in the theoretical formulation to predict the shell side mass transfer coefficient of CO_2 from a gas mixture, as discussed later.

doi:10.1016/j.proeng.2012.08.825

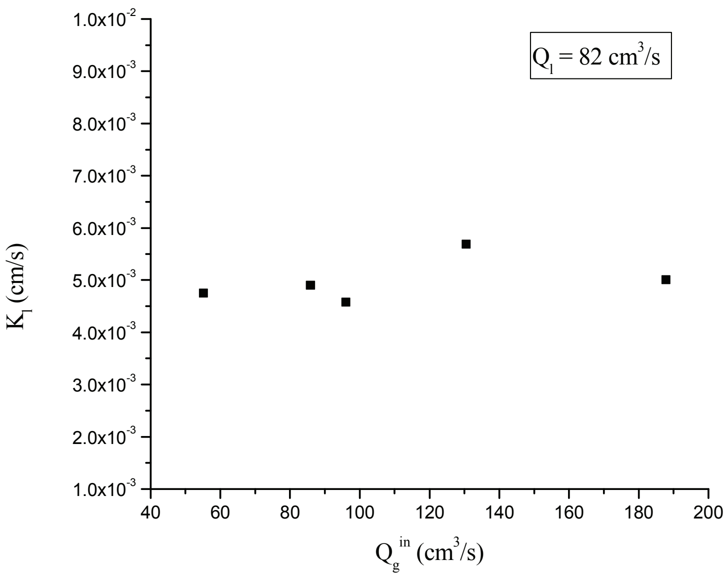

Figure 1. Pure CO_2 absorption in water: Variation of the overall mass transfer coefficient with gas flow rate at constant liquid flow rate.

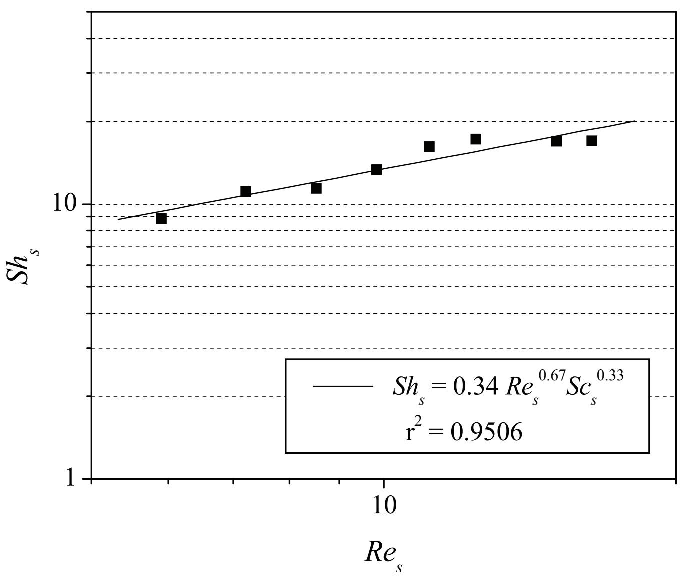

Figure 2. Pure CO_2 absorption in water: Variation of shell side Sherwood number with shell side Reynolds number and curve fitting of shell side mass transfer correlation.

Experimental investigation of the physical and chemical absorption of CO_2 from a gas mixture, in a wide range of gas and liquid flow rate and concentration, established the Liqui-Cel® Extra-Flow membrane operational flexibility. The membrane control under real conditions was achieved by using gas and liquid solvents of industrial use and hence, of low purity. The comparison of the experimentally measured absorption performance in the commercial cross-flow membrane to the performance of parallel flow membrane contactors used in the literature [5], presented in Table 1, confirmed the effectiveness of the former. The Liqui-Cel® Extra-Flow geometric configuration assures transverse flow in the shell side, without problems of fluid mal-distribution and results to improved mass transfer, compared to parallel flow contactors.

Table 1. Comparison of CO_2 absorption performance in a cross-flow and a parallel flow membrane contactor

Experimental results **Cross-flow membrane** a_m = 29.3 cm^{-1}			**Literature results** **Parallel flow membrane** a_m = 37.0 cm^{-1}		
Q_g (cm^3/s)	Q_l (cm^3/s)	$K_{ol}a_m$ (s^{-1})	Q_g (cm^3/s)	Q_l (cm^3/s)	$K_{ol}a_m$ (s^{-1})
15% CO_2 - water			1-10% CO_2 - water		
5.5*10^1	3	**4.0*10^-2**	5.4*10^1	14	**1.4*10^-2**
	37	**12.2*10^-2**		25	**1.7*10^-2**
1.0*10^2	13	**4.7*10^-2**	1.0*10^2	14	**1.4*10^-2**
	25	**8.2*10^-2**		25	**1.7*10^-2**
15% CO_2 - 0.5 M DEA			1-10% CO_2 - 0.5 M DEA		
5.5*10^1	41	**0.295**	4.2*10^1	18	**0.389**
	66	**0.399**		21	**0.386**
1.1*10^2	35	**0.606**	4.6*10^1	18	**0.415**
	63	**0.741**		21	**0.409**

A mathematical model for the simulation of membrane-based contacting process in the cross-flow Liqui-Cel® Extra-Flow module was developed taking into account the operating conditions, the membrane properties and characteristics, the lumen fluid dynamic and the flow configuration in the shell side through the experimentally resulted mass transfer correlation. Comparison of model predictions with the experimental results established the model validity, as shown in Figure 3 where the CO_2 gas outlet concentration is plotted versus the gas and absorbent flow rate. The proposed correlation predicted the shell side mass transfer performance of the Liqui-Cel® Extra-Flow membrane for a wide Reynolds number range, resulting in better theoretical representation of CO_2 absorption in water compared to published correlation used in our previous study [6].

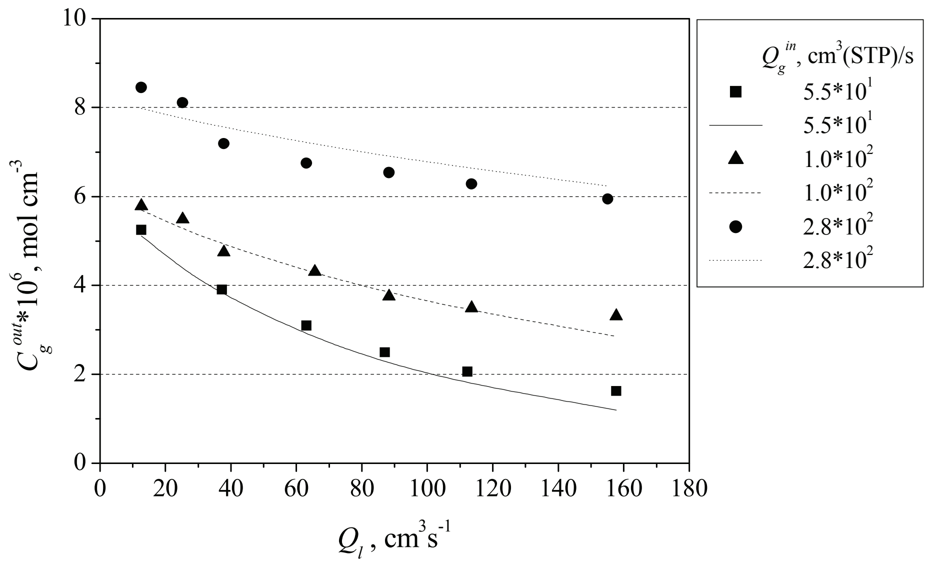

Figure 3. 15% CO_2 absorption in water: Comparison between theoretical (curves) and experimental (symbols) results of CO_2 gas outlet concentration at different gas and liquid flow rates.

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Keywords: Membrane contactor, Cross-flow, Mass transfer correlation, Modelling